



VRB Power Systems
INCORPORATED

Vanadium Redox Batteries **Technical Introduction**

What is a VRB Energy Storage System?

- **An electrochemical *energy storage system***
- **A flow battery, based on Vanadium as the only element – electrolyte cross-contamination not an issue**
- **Based on the reduction and oxidation of the different ionic forms of Vanadium**
- **Energy (electricity) can be stored indefinitely in a liquid – very low self-discharge**
- **Energy can be recovered instantaneously (< 10ms)**

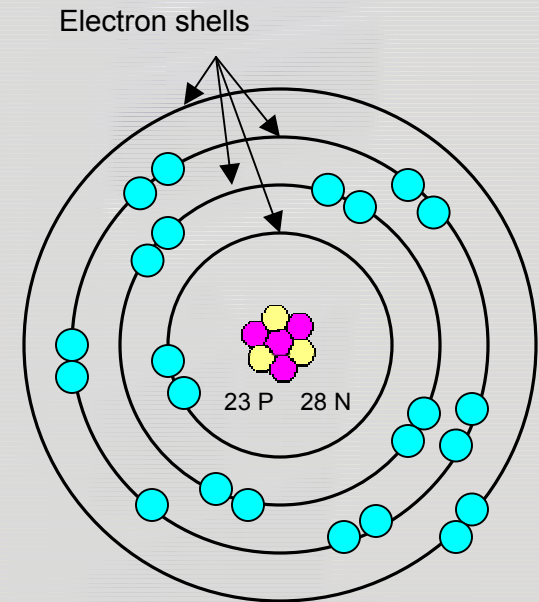
What is Vanadium?

Vanadium is the
23rd element in the
periodic table

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Vanadium is a silverish *transition metal* (the valence electrons exist in more than one shell). In normal states, vanadium atoms have 23 protons, 23 electrons, and 28 neutrons.

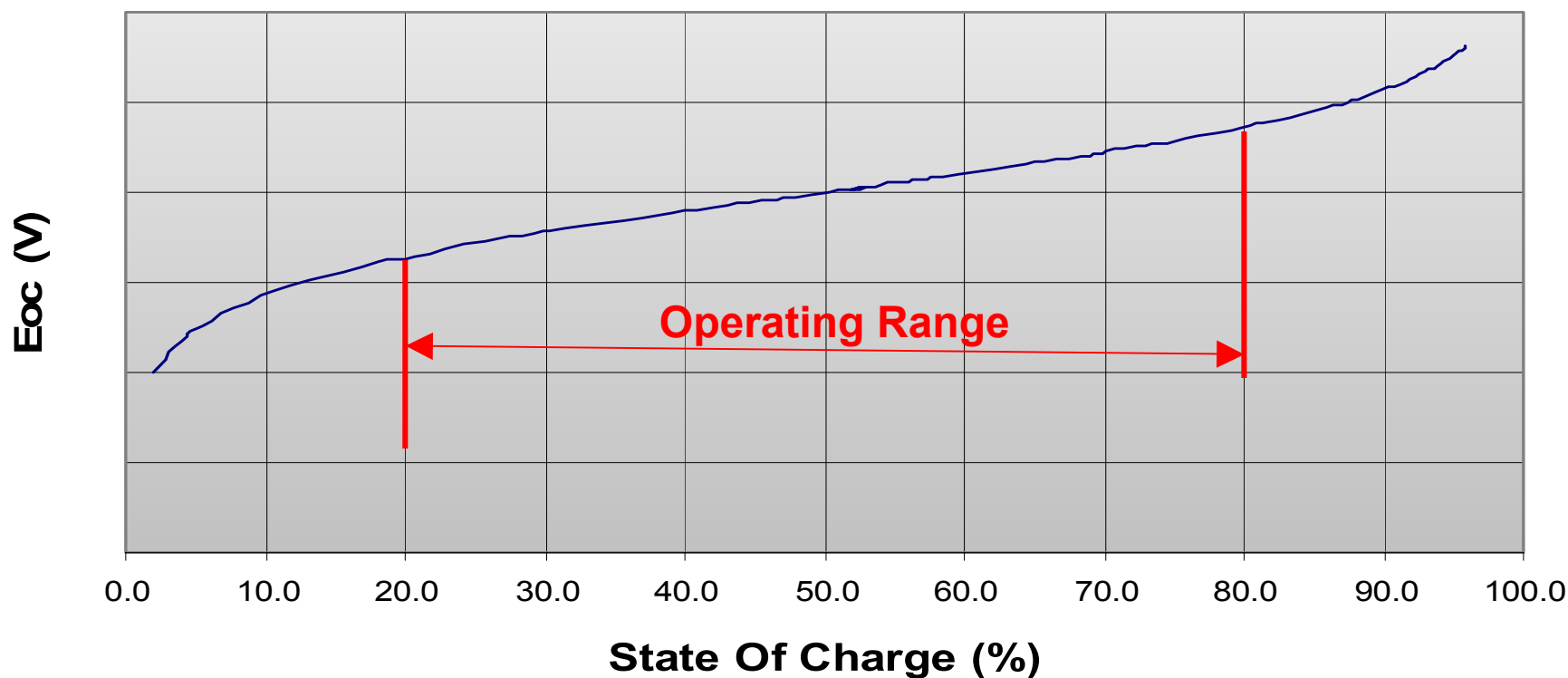
Vanadium is found all over the world. Vanadium is added to iron, steel, and titanium to add strength, improve durability, and resist wear and temperature.



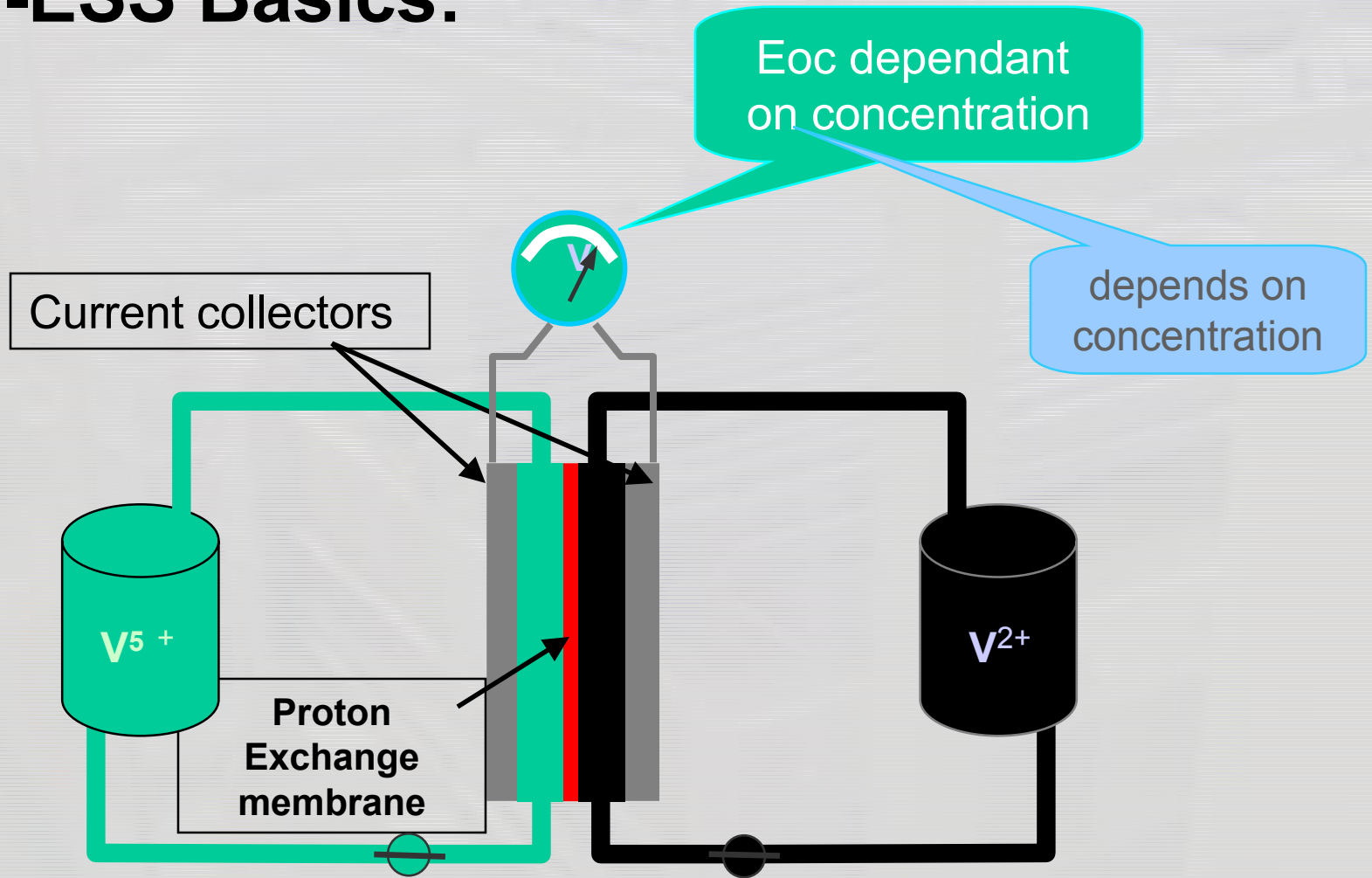
VRB cell open circuit voltage (Eoc)

State-of-Charge (SOC) indicator

Nerntz Curve (SOC vs Eoc)



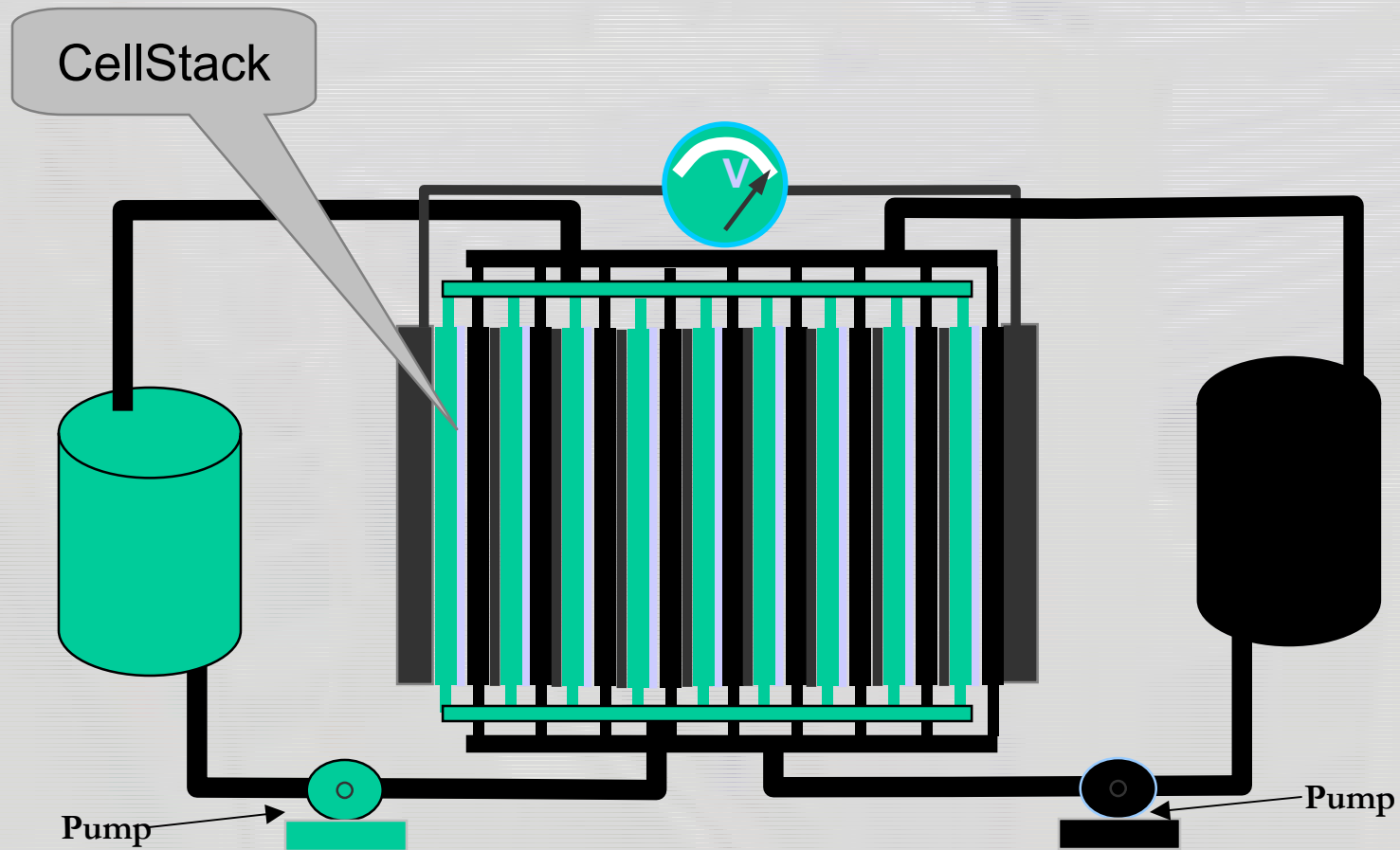
VRB-ESS Basics:



Operating Parameters

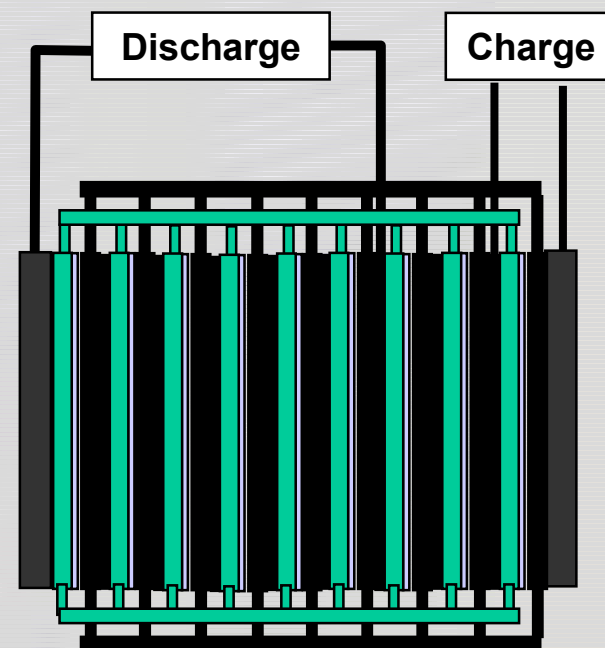
- **Electrolyte Operating Temperature Range: up to 104 deg F**
- **Vanadium concentration: 1 to 2.5 Mole/liter**
- **Sulfuric acid concentration: 1 to 4 Mole/liter**
- **Electrolyte Hazardous classification: Non-toxic**
- **Specific Gravity: Dependant upon concentration**
- **Speed of response: <10ms**

VRB-ESS

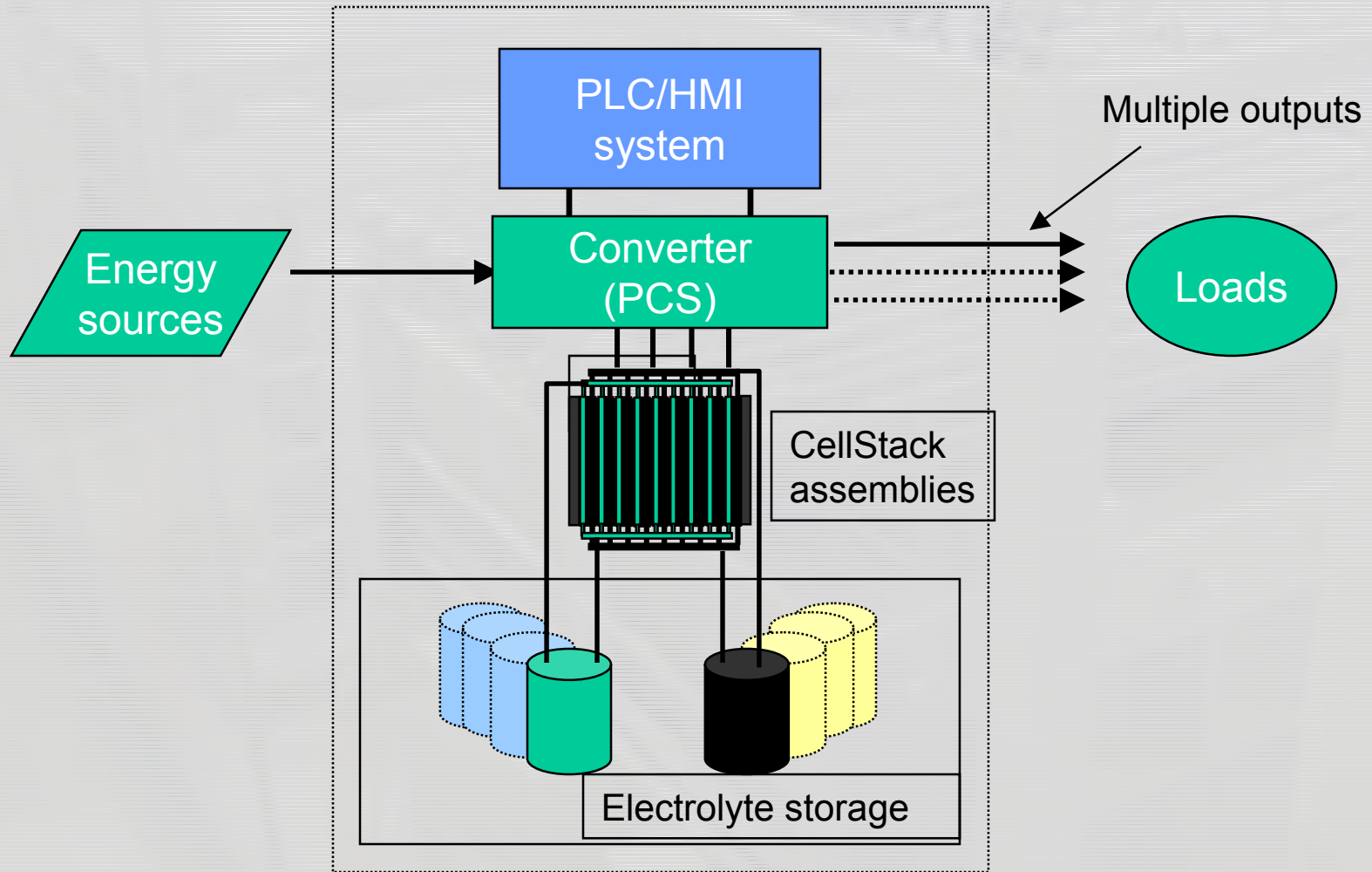


VRB-ESS Characteristics

- Can separate discharge & charge functions
 - simultaneous discharge & charge
 - chemical DC-DC converter
- Can separate stack & electrolyte bulk storage
 - physically
 - functionally



VRB-ESS Components



Technical Advantages of VRB-ESS

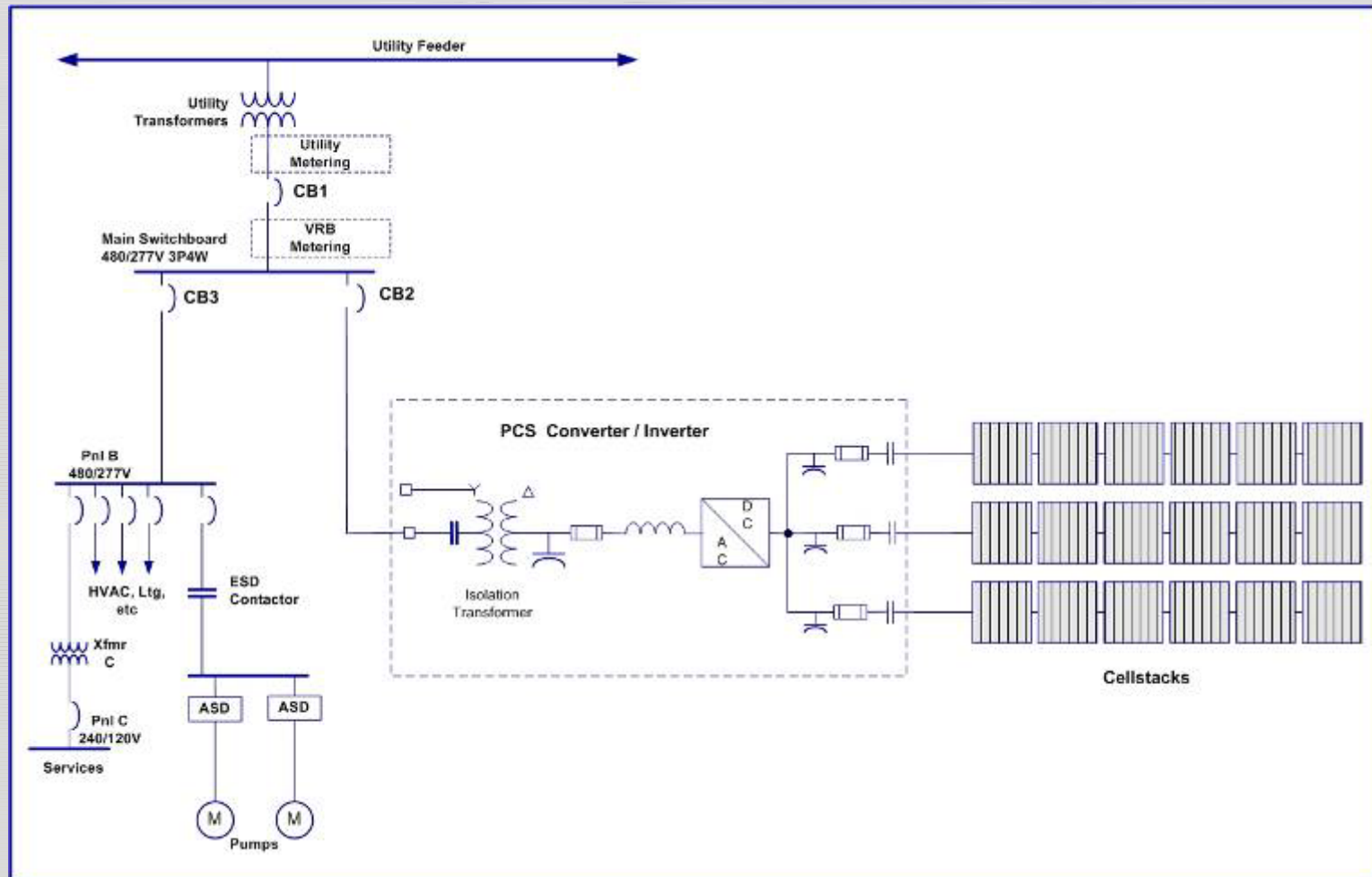
- **High-energy efficiencies of >75% (AC to AC) and >85% (DC to DC)**
- **Very Low Self Discharge. Will remain fully charged almost indefinitely.**
- **Storage capacity can be increased by increasing electrolyte volume; no change to battery cellstacks.**
- **Designed for unattended operation. Low operating and maintenance costs.**
- **Cross mixing of electrolytes does not cause contamination. Same electrolytes on both sides of battery.**
- **Can be charged and discharged > 13,000 cycles without need for membrane replacement.**
- **Together with PCS (Power Conversion System) can provide power quality improvements.**
- **High rate of Charging: Same rate as Discharge.**

Environmental Advantages

The Green Battery

- **No heavy metals such as lead, nickel, zinc and cadmium**
- **Low environmental impact during life cycle.**
- **Electrolytes used in the VRB-ESS have indefinite life**
 - **No disposal issues**
 - **Completely reusable**

Single Line Diagram



CellStacks



VRB Power Systems Inc.
Energy Storage & Power Quality Solutions

Final Installation



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Storage Tanks



Applications of VRB-ESS

- Capital deferral of Transmission & Distribution
- Load leveling – max demand reductions
- Arbitrage (By Low Sell High)
- PQ and energy management (Not PQ alone)
- Provision of ancillary services to utilities or PFC to end users
- Integration with renewables to deliver capacity and enhance efficiency
- RAPS (Remote Area Power Supply)

